

Chapter 4. Bandelier National Monument

Introduction

Bandelier was declared an archeological monument by the U.S. Department of Agriculture (USDA) in 1916 as part of the Santa Fe National Forest. The Monument was named in honor of Adolf Bandelier, an archeologist of the late 1800's who worked extensively in the region. The Presidential proclamation stated:

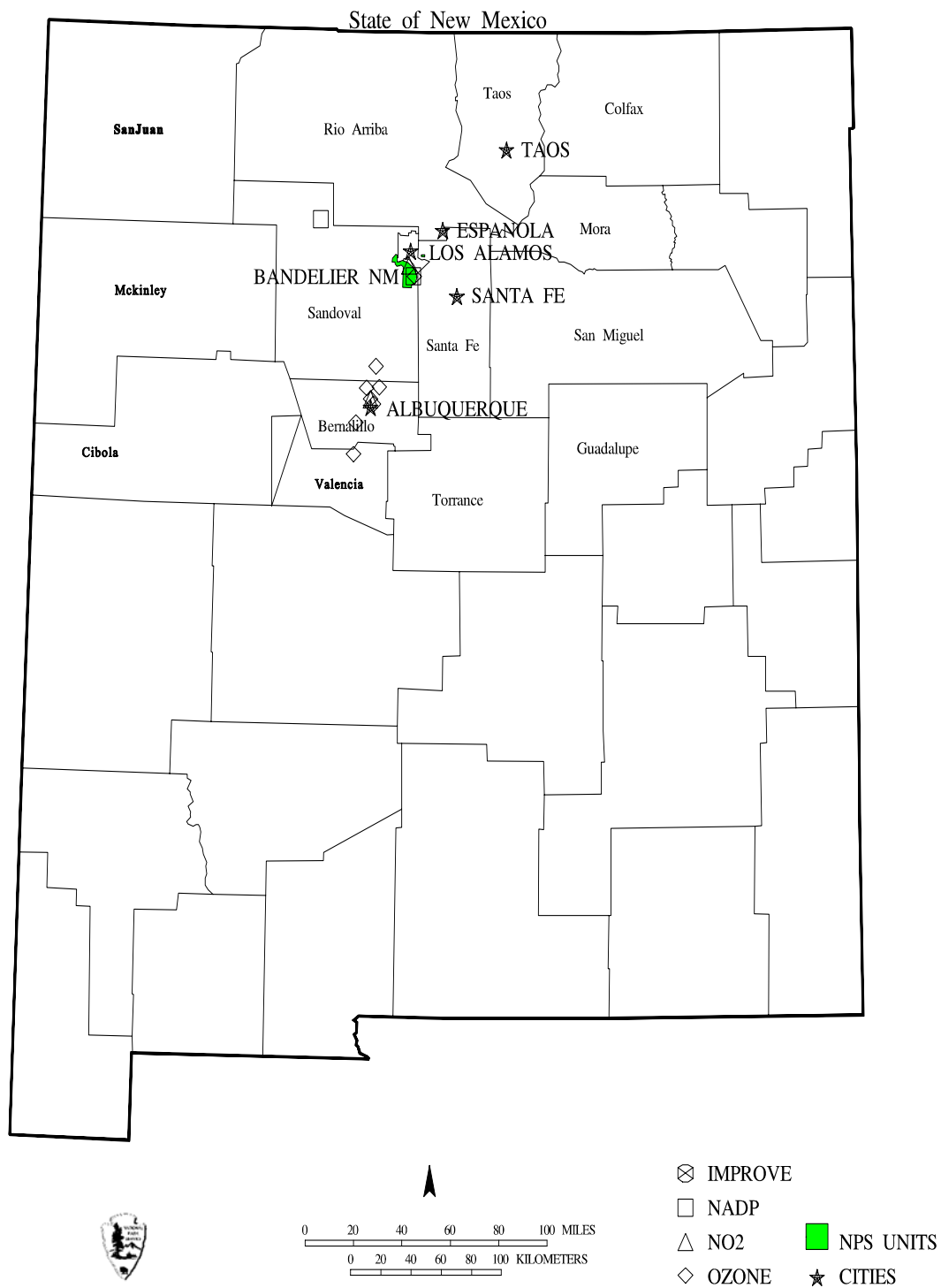
" Certain prehistoric aboriginal ruins.., are of unusual ethnologic, scientific, and educational interest, and it appears that the public interests would be promoted by reserving these relics of vanished people, with as much land as may be possible for the proper protection there of..."

In 1932 the Monument was reassigned from the Forest Service to the NPS in the Department of Interior. Bandelier National Monument covers approximately 13,250 ha of federally owned land (Figure 4-1). In 1972, the unique and valuable natural resources of Bandelier were officially recognized and the Bandelier Wilderness was created, comprising 9,425 ha of the Monument. The elevation of Bandelier ranges from 1,590 m at the Rio Grande to 3,190 m at the summit of Cerro Grande. Bandelier is located on the southern portion of the Pajarito Plateau on the eastern flank of the Jemez Mountains, a range forming the southern edge of the Rocky Mountains. The Monument has portions in Sandoval, Los Alamos and Santa Fe counties, and is adjacent to Los Alamos National Laboratory. The Anasazi occupied the region of the Park between about 1100 and 1600 A.D. and their culture left an incredible density of sites (an average of 1 site/2.7 ha).

Geology and Soils

The region surrounding Bandelier has been shaped by faulting that started as early as 30 million years ago. This late Cenozoic Era faulting resulted in the Rio Grande Rift, and widespread intrusions and volcanism from late in the Tertiary Period into the Pleistocene. About 1 million years ago, an intense volcanic event formed what is now the Jemez Caldera and released tremendous volumes of ash and pumice while fragmenting and displacing huge amounts of basaltic rock. The ash flows became the Bandelier Tuff that forms most of the walls of Frijoles and surrounding canyons. The differential cooling and cementing of this 30 m thick layer of tuff resulted in material

Figure 4-1. Location of Bandelier National Monument.



that spatially varies in its resistance to weathering; the slower-cooling middle is more resistant to erosion than either the top or bottom of the layer. This variability has resulted in the alternating mesa and canyon topography of the region and of the Monument. The relatively soft and poorly consolidated material allowed prehistoric people to carve homes and granaries out of small caves and alcoves that formed naturally along the side walls of the region's canyon (Chronic 1986).

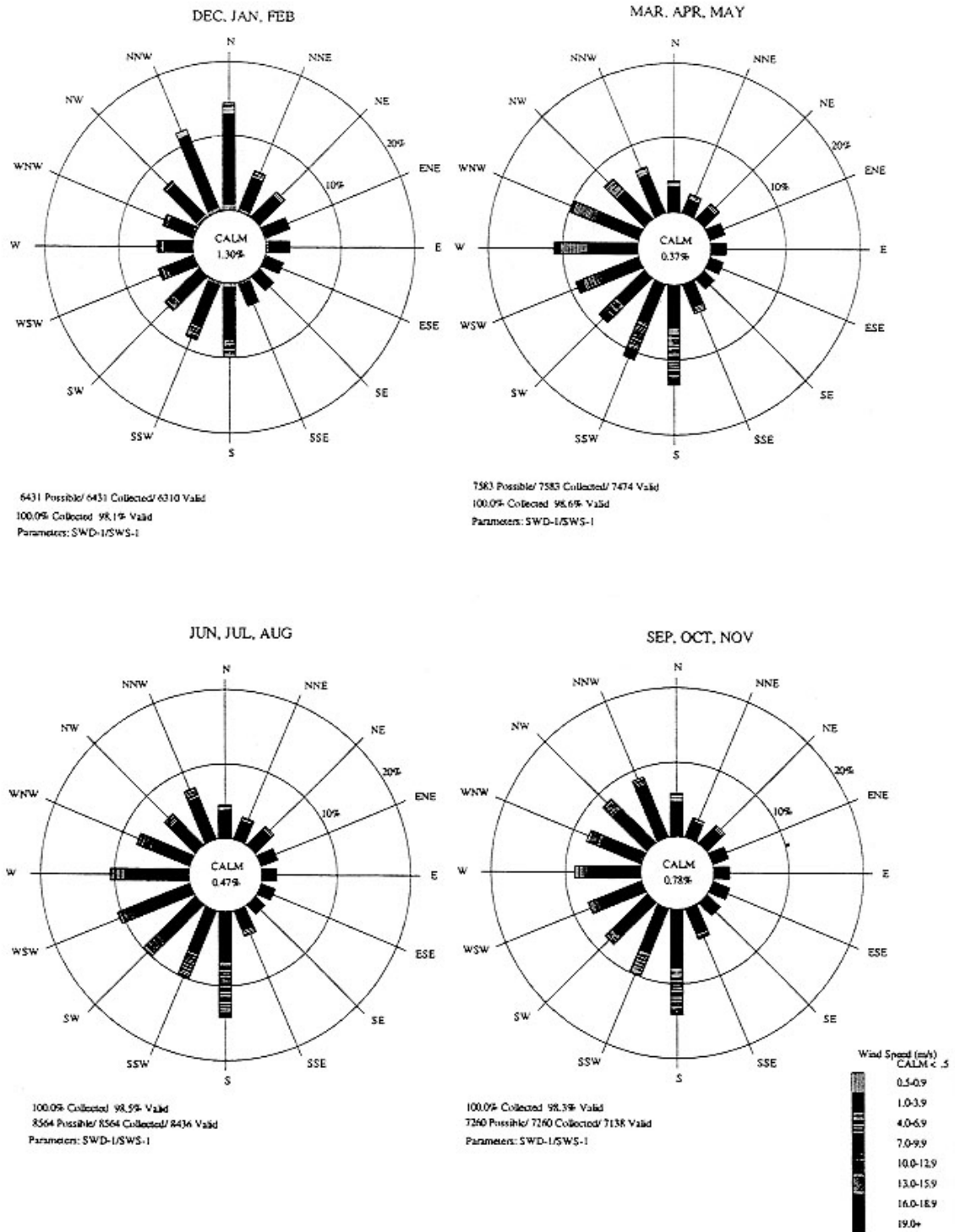
Soils in Bandelier are variable and range from soils derived mostly from rhyolitic tuff or pumice to cobbly colluvial and alluvial soil material at the foot of canyon walls. Over most of the southern portion of the Monument, soils are derived from the volcanic rhyolitic tuff and are thin and easily eroded. This erosion is currently a major concern for the Monument, especially in the pinyon/juniper zone which occurs throughout much of the park. Erosion is believed to have been accelerated by over-grazing in historic times by cattle and feral burros. Most soils are somewhat fertile, with relatively high concentrations of available base cation nutrients. Some mesa-top soils are more stable, moderately deep to deep, and are more weathered with higher organic content than soils found in other parts of the Monument.

Climate

Bandelier has a semi-arid to sub-humid climate, receiving an average of 410 mm/yr of precipitation (ranging from 340 mm/yr at lower elevation to 650 mm/yr at higher elevations). Lower elevation sites receive rain in July and August, and higher elevation sites also receive winter precipitation. The mean annual temperature is 10° C with higher elevation sites being cooler. At the visitor center, the winds in winter come primarily from the north and from the west, shifting more westward and southward in the other seasons (Figure 4-2). In the western end of Bandelier, stronger winds are predominantly from the northwest reflecting a dominant drainage flow out of the Jemez mountains while variation in lighter winds is considerable. The eastern end of Bandelier receives winds primarily from the south because of air channeling through the Rio Grande Depression. This southerly flow from Albuquerque is particularly important for air quality.

Figure 4-2. Seasonal wind roses for Bandelier National Monument (1990-1993).

Figure 4-2. Seasonal wind roses for Bandelier National Monument (1990-1993).



Vegetation

The dry climate at Bandelier strongly controls the species composition of communities and the relative abundances of species. Most of the vegetation cover in Bandelier has been mapped, and several studies have examined the impacts of disturbance on plant communities. Bandelier National Monument is characterized by several dominant plant community types. Pinyon (*Pinus edulis*)/juniper (*Juniperus monosperma*, *J. scopulorum*), covering about 5,300 ha, and ponderosa pine (*Pinus ponderosa*)/mixed conifer are the dominant vegetation types in the Monument followed by grasslands, meadows and mountain mahogany (*Cercocarpus montanus*)/Apache plume (*Fallugia paradoxa*) shrublands. At higher elevations on north slopes, mixed conifer grades to Douglas-fir (*Pseudotsuga menziesii*)/white fir (*Abies concolor*)/aspen (*Populus tremuloides*) and Douglas-fir/Engelmann spruce (*Picea engelmannii*). Species commonly found in grassland communities and in the understory of the woody plant communities include: blue grama (*Bouteloua gracilis*), black grama (*Bouteloua eriopoda*), bluestem (*Andropogon* spp.), and galleta grass (*Pleuraphis jamesii*). Bluegrass (*Poa* spp.), Junegrass (*Koeleria nitida*), mountain brome (*Bromus* sp.), mountain muhly (*Muhlenbergia montana*) and Arizona fescue (*Festuca arizonica*) occur on mesas and at higher elevations. The lichens and microphytic soil crusts of Bandelier are recognized as important components of native ecosystems and have been objects of research interest (Loftin and White *in press*, Chong 1992, Weber 1980). Complete lists of Monument flora are found in NPFlora and are also provided by Potter and Foxx (1979). Lichen lists can be found in NPLichen, Jones (1979) and Wetmore (1983). There are no known Threatened and Endangered Plant Species (Threatened and Endangered Species Information Institute 1993), or NPS species of special concern. One animal species of special concern to the NPS occurs in the Monument: *Plethodon neomexicanus*, the Jemez Mountain salamander.

Air Quality

Air quality monitoring for Bandelier consists of data from 1990-1994 for ozone concentration, NADP monitoring from 1982 to the present, sulfur dioxide measurements from 1988-1994, and IMPROVE monitoring for visibility from 1988 to the present.

Emissions

Table 4-1 provides summaries for emissions of carbon monoxide (CO), ammonia (NH₃), nitrogen oxides (NO_x), volatile organic compounds (VOC), particulate matter (PM), and sulfur oxides (SO_x) for 15 counties surrounding Bandelier National Monument. No information is available to relate these emissions to air quality at Bandelier, or to apportion Bandelier's air quality impairment to local and regional sources. The largest local producers of SO_x in San Juan County include two power plants (Arizona Public Service's 4 Corners plant, and Public Service Company's San Juan Generating plant) and Western Gas Processors' San Juan facility.

Table 4-1. 1994 Emissions (tons/day) for counties surrounding Bandelier National Monument (Radian 1994).

County	CO	NH ₃	NO _x	VOC	PM	SO _x
Bernalillo, NM	581.1	1.45	98.21	9.06	229.65	13.87
Cibola, NM	6.24	0.07	4.44		199.37	2.32
Colfax, NM	24.95	1.14	4.14	38.21	34.07	1.54
Guadalupe, NM	15.06	1.04	2.09	23.8	27.35	0.22
Los Alamos, NM	14.35	0.04	1.58	1.25	5.36	0.16
McKinley, NM	151.19	2.22	40.84	47.42	319.85	7.99
Mora, NM	16.87	0.66	1.89	18.62	24.89	0.21
Rio Arriba, NM	91.03	1.32	15.92	71.56	263.55	1.29
Sandoval, NM	91.72	0.22	13.37	36.34	176.17	1.42
San Juan, NM	166.63	1.17	196.56	50.16	371.94	175.53
San Miguel, NM	44.77	1.32	6.04	46.82	53.13	0.88
Santa Fe, NM	144.44	0.44	19.84	16.90	141.74	2.19
Taos, NM	64.17	0.43	8.25	23.87	92.19	0.96
Torrance, NM	26.13	1.32	5.61	27.59	44.10	0.37
Valencia, NM	127.07	0.77	16.77	56.02	213.12	1.84

Air Pollutant Concentrations

The concentrations of ozone between 1990 and 1994 averaged about 50 ppb, with peak 1-hr concentrations of 75 to 90 ppb (Table 4-2). These concentrations fall within a range that may produce visible injury or growth effects on very sensitive species (see Chapter 2), but no effects have been noted. The concentrations of SO₂ were far below any threshold of suggested sensitivity for any plants.

Table 4-2. Concentrations of ozone and SO₂ for Bandelier National Monument between May and September. For ozone, upper value is mean daily concentration (ppb); middle number is the Sum60 exposure (ppb-hr in excess of 60 ppb for 12 hr/day for 3 months); and bottom number is the maximum 1-hr concentration observed each year. SO₂ measured 24-hr/day by IMPROVE filter samplers (ppb) (1 µg/m³ approximately equals 0.38 ppb). Ozone data from the NPS Air Resources Division's Quick Look Annual Summary Statistics Reports (provided by D. Joseph, NPS-ARD).

Year	Ozone	SO ₂
1988	--	
Mean		0.1
Sum60		
Max		1.9
1989	--	
Mean		0.1
Sum60		
Max		0.5
1990		
Mean	48	0.1
Sum60	15199	
Max	81	0.5
1991		
Mean	48	0.0
Sum60	28265	
Max	87	0.6
1992		
Mean	46	0.1
Sum60	13070	
Max	78	0.3
1993		
Mean	44	
Sum60	8490	
Max	77	
1994		
Mean	46	
Sum60	19155	
Max	90	

Visibility

Bandelier National Monument is about 64 km west of Santa Fe, and 80 km northwest of Albuquerque. Visual air quality has been monitored since 1988, using a transmissometer, an aerosol sampler and a camera at locations near the fire lookout on Frijoles Mesa. The camera operated from July 1978 to April 1995. Bandelier National Monument is part of the IMPROVE Monitoring Network. The data from this IMPROVE site have been summarized to characterize the full range of visibility conditions for the period May 1988 through February 1994, based on seasons of spring (March, April, May), summer (June, July, August), autumn (September, October, November), and winter (December, January, February).

Optical Data - Transmissometer

The transmissometer system consists of two individually-housed primary components: a transmitter (light source) and a receiver (detector). The atmospheric extinction coefficient (b_{ext}) at any time can be calculated based on the intensity of light emitted from the source and that measured by the receiver (along with the path length between the two). Transmissometers provide continuous, hourly b_{ext} measurements. Weather factors such as clouds and rain can affect transmissometer measurements, but these can be "filtered out" by removing data points with high relative humidities ($\text{RH} > 90\%$).

The data are presented by season and annual median values, with and without meteorological factors, in Table 4-3. The data are presented in units of extinction coefficient in Mm^{-1} and standard visual range in km. Extinction coefficients represent the ability of the atmosphere to scatter and absorb light. Median values with large differences between the extinction values "including weather" and "excluding weather" indicate periods dominated by precipitation. Higher extinction coefficients signify lower visibility. Similarly, season and annual medians with nearly equal "including weather" and "excluding weather" extinctions indicate visibility reduction caused principally by particles.

Table 4-3. Transmissometer data summary for Bandelier National Monument for 1988-1994. SVR = standard visual range; b_{ext} = light extinction coefficient.

Season Year	Excluding Weather		Including Weather	
	Median of All Data		Median of all Data	
	SVR (km)	b_{ext} (Mm^{-1})	SVR (km)	b_{ext} (Mm^{-1})
Autumn 1988	142	27	137	28
Winter 1989	153	25	142	27
Spring 1989	110	35	104	37
Summer 1989	107	36	99	39
Autumn 1989	124	31	120	32
Annual 1989	120	32	113	34
Winter 1990	120	34	113	34
Spring 1990	117	33	110	35
Summer 1990	107	36	107	36
Autumn 1990	153	25	148	26
Annual 1990	120	32	113	34
Winter 1991	148	26	142	27
Spring 1991	124	31	124	31
Summer 1991	113	43	110	35
Autumn 1991	107	36	99	39
Annual 1991	120	32	113	34
Winter 1992	124	31	113	34
Spring 1992	117	33	110	35
Summer 1992	104	37	102	38
Autumn 1992	110	35	107	36
Annual 1992	110	35	107	36
Winter 1993	113	34	94	41
Spring 1993	124	31	120	32
Summer 1993	133	29	128	30

Autumn 1993	102	38	99	39
Annual 1993	117	33	110	35
Winter 1994	107	36	104	37
Spring 1994	102	38	99	39
Summer 1994	117	33	117	33
Autumn 1994	137	28	133	29
Annual 1994	117	33	113	34

No trends were apparent between 1988 and 1994. Visibility tends to be lower in spring and summer than in winter, including or excluding high humidity days (Table 4-4).

Table 4-4. Standard visual range for Bandelier National Monument. Seasonal averages for median standard visual range in km from October 1988 - November 1994.

Season	Excluding Weather	Including Weather
Winter	127	118
Spring	116	111
Summer	114	110
Autumn	125	120

Aerosol Data

Aerosol sampler data are used to reconstruct the atmospheric extinction coefficient from experimentally determined extinction efficiencies of certain species (Table 4-5). To compare this table with the data from Table 4-3 and 4-4, the "excluding weather" values should be used. The estimated visual ranges and light extinction coefficients are similar for both the transmissometer measurements and the reconstructed values based on aerosol concentrations. In Table 4-6 the data are presented as seasonal and annual 50th and 90th percentile standard visual range for Bandelier National Monument. The 50th percentile means that visual range is this high or lower 50% of the time. This is an average 50th percentile for each season. The 90th percentile means

that the visual range is this high or lower 90% of the time. This is an average 90th percentile for each season.

The reconstructed extinction data are used as background conditions to run plume and regional haze models. These data are also used in the analysis of visibility trends and conditions. The measured extinction data are used to verify the calculated reconstructed extinction and can also be used to run plume and regional haze models and to analyze visibility trends and conditions. Because of the larger spatial and temporal range of the aerosol data, reconstructed extinction data are preferred.

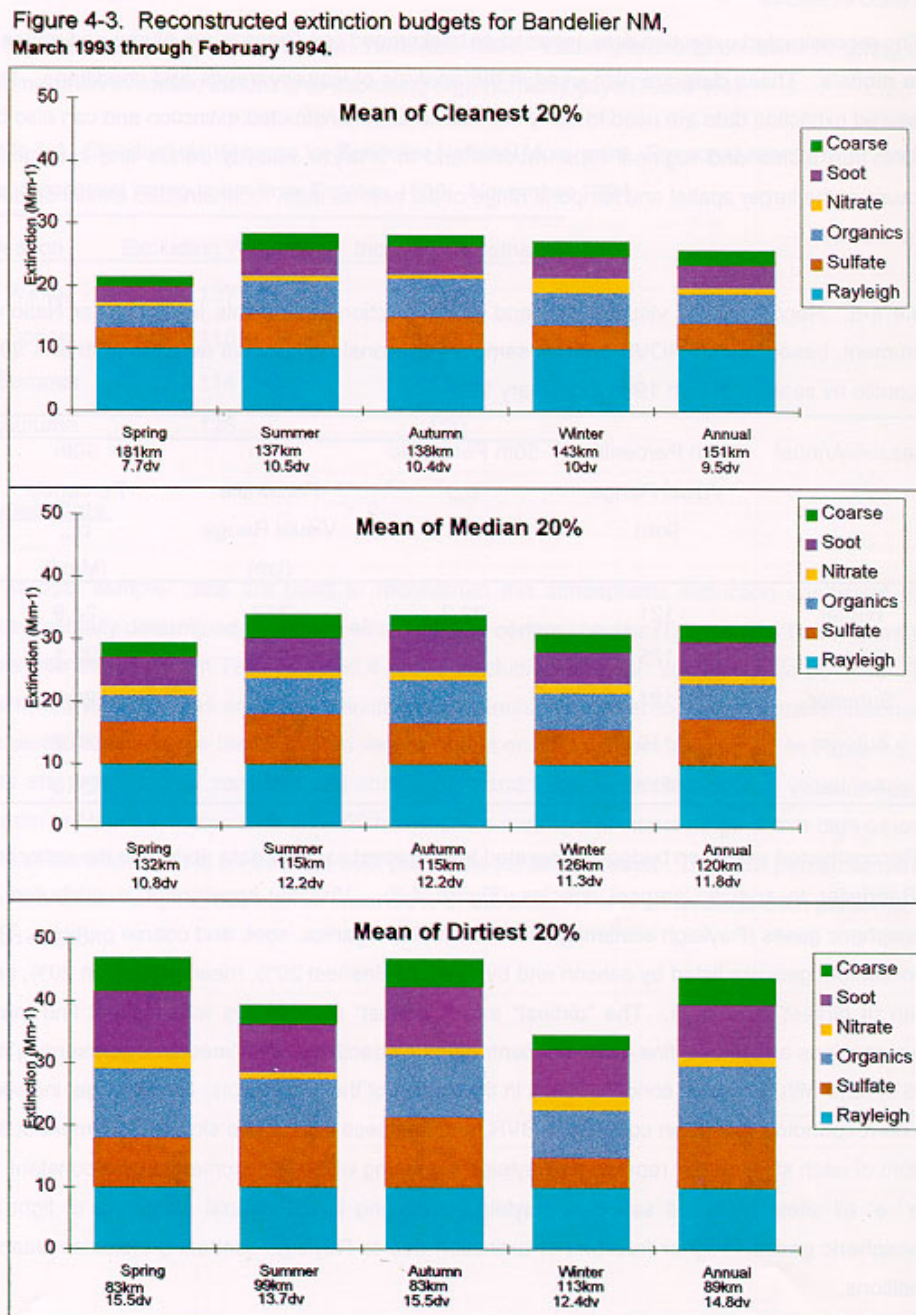
Table 4-5. Reconstructed visual range and light extinction coefficients for Bandelier National Monument, based on IMPROVE aerosol sampler, seasonal and annual average 50th and 90th percentile by season, March 1988 - February 1994.

Season/Annual	50th Percentile Visual Range (km)	50th Percentile b_{ext} (Mm^{-1})	90th Percentile Visual Range (km)	90th Percentile b_{ext} (Mm^{-1})
Winter	121	32.3	157	24.9
Spring	125	31.4	177	22.1
Summer	121	32.3	149	26.2
Autumn	115	33.9	152	25.7
Annual	117	33.5	158	24.8

Reconstructed extinction budgets generated from aerosol sampler data apportion the extinction at Bandelier to specific aerosol species (Figure 4-3). Visibility impairment is attributed to atmospheric gases (Rayleigh scattering), sulfate, nitrate, organics, soot, and coarse particles. The extinction budgets are listed by season and by mean of cleanest 20%, mean of median 20%, and mean of dirtiest 20% days. The "dirtiest" and "cleanest" signify days with highest fine mass concentrations and lowest fine mass concentrations respectively, with "median" representing the

20% of days with fine mass concentrations in the middle of the distribution. Each budget includes the corresponding extinction coefficient, SVR, and haziness in dv. The sky blue segment at the bottom of each stacked bar represents Rayleigh scattering which is assumed to be a constant 10 Mm^{-1} at all sites during all seasons. Rayleigh scattering is the natural scattering of light by atmospheric gases. Higher fractions of extinction due to Rayleigh scattering indicates cleaner conditions.

Figure 4-3. Reconstructed extinction budgets for Bandelier National Monument, March 1993 through February 1994.



Atmospheric light extinction at Bandelier, like many rural western areas, results primarily from aerosols of sulfate, organic compounds, and soot. In pre-industrial times, visibility would vary with

patterns in weather, winds (and the effects of winds on coarse particles), and fires. We have no information on how the distribution of visibility conditions at present differs from the profile under “natural” conditions.

Photographs

Three photos are provided to represent the range of visibility conditions at Bandelier (Figure 4-4). The photos were chosen to provide a feel for the range of visibility conditions possible and to help relate the SVR/extinction/haziness numbers to what people see.

Figure 4-4. Photographs representing visibility conditions at Bandelier National Monument.

Bandelier National Monument
on a "clear" day.

Representative Conditions:
Visual Range: 350 - 391 km
 b_{ext} : 11 - 10 Mm^{-1}
Haziness: 1 - 0 dv



Bandelier National Monument
on a "average" day.

Representative Conditions:
Visual Range: 200 - 240 km
 b_{ext} : 20 - 16 Mm^{-1}
Haziness: 7 - 5 dv



Bandelier National Monument
on a "dirty" day.

Representative Conditions:
Visual Range: 100 - 120 km
 b_{ext} : 39 - 33 Mm^{-1}
Haziness: 14 - 12 dv



Atmospheric Deposition

The rates of atmospheric deposition for Bandelier are low (Table 4-6). Precipitation pH averages about 5.0. Deposition of N averages about $1.5 \text{ kg N ha}^{-1} \text{ yr}^{-1}$, which is similar to the rate of S deposition. No trend is apparent for the concentration or deposition of N, but S concentrations and deposition have declined since the late 1980s (see also Lynch et al. 1996). There is no evidence that such low levels of deposition pose any threat to plants (see Chapter 2).

Table 4-6. Atmospheric deposition for Bandelier National Monument (NADP). Note the values for N and S compounds include the whole molecule and not just the N or S atoms.

	Concentrations (mg/L)			Deposition ($\text{kg ha}^{-1} \text{ yr}^{-1}$)				Conductivity ($\mu\text{S/mm}$)	Precipitation (mm/yr)
year	NH ₄	NO ₃	SO ₄	NH ₄	NO ₃	SO ₄	pH		
1982	0.18	0.61	1.03	0.64	2.17	3.66	5.15	0.79	356
1983	0.16	0.86	1.01	0.59	3.18	3.74	5.06	0.89	370
1984	0.17	0.90	1.03	0.63	3.36	3.84	5.03	0.90	373
1985	0.12	0.71	0.90	0.67	3.94	5.00	5.04	0.79	556
1986	0.11	0.71	0.90	0.62	4.02	5.09	5.01	0.80	566
1987	0.16	1.07	1.00	0.61	4.09	3.82	4.91	1.00	382
1988	0.05	0.78	0.89	0.26	4.10	4.68	4.89	0.91	526
1989	0.20	1.07	0.91	0.77	4.11	3.49	4.92	0.98	384
1990	0.19	0.77	0.80	0.75	3.05	3.17	5.06	0.80	396
1991	0.14	0.75	0.67	0.77	4.15	3.70	5.05	0.72	553
1992	0.16	0.76	0.74	0.57	2.69	2.62	5.07	0.74	354
1993	0.15	0.76	0.70	0.70	3.56	3.28	5.00	0.78	469
1994	0.15	0.86	0.66	0.67	3.83	2.94	4.96	0.81	445

Sensitivity of Plants

No signs of injury from air pollution have been reported for vegetation in or near Bandelier National Monument. Only a few of the Monument's species have been tested under controlled conditions for sensitivity to pollutants, and none of these tests included genotypes representative of the plants in the Monument. Based on the ozone concentrations required to affect very sensitive plants (such as aspen), we expect that current ozone exposures could be high enough to affect some species. Current levels of ozone are probably too low to affect the conifers (with the possible exception of ponderosa pine), and levels of SO₂ are far below any demonstrated threshold of sensitivity for any plants. In the absence of empirical evidence of any effects, no substantial problem is likely.

Water Quality and Aquatic Organisms

Bandelier National Monument is located on a plateau which is cut by three stream drainages: Frijoles, Alamo, and Capulin Canyons. Frijoles Canyon contains a permanent stream, El Rio de los Frijoles; Capulin Creek flows year round only in the upper third of the canyon, and Alamo Creek carries permanent water only in the northern part of its canyon. A portion of the Rio Grande runs through the Monument on its eastern border. Some water quality monitoring of streams and rivers in the Monument has been carried out as part of the National Water Quality Assessment of the U.S. Geological Survey.

Water quality data were collected in Bandelier June 1977-September 1978 (following the Mesa fire) by Purtymun and Adams (1980). The range of pH reported for the Rio Grande was 8.3-8.5. The stream reaches within the monument had pH values of 7.3-8.5. The bicarbonate buffering and ANC were very high for both the river and the streams: bicarbonate buffering capacity of 139-156 mg/l (2780-3120 µeq/L ANC) for the Rio Grande and 40-85 mg/L (800-3700 µeq/L) bicarbonate for the stream reaches. A map of sample locations within the Monument is included in Figure 4-5, and Table 4-7 provides representative water quality data for major creek drainages collected by Purtyman and Adams (1980). The buffering in the Rio Grande and surface streams of the Monument is sufficient to prevent any change in pH due to acidic deposition.

Figure 4-5. Streams of Bandelier National Monument (area burned in La Mesa fire is shaded).

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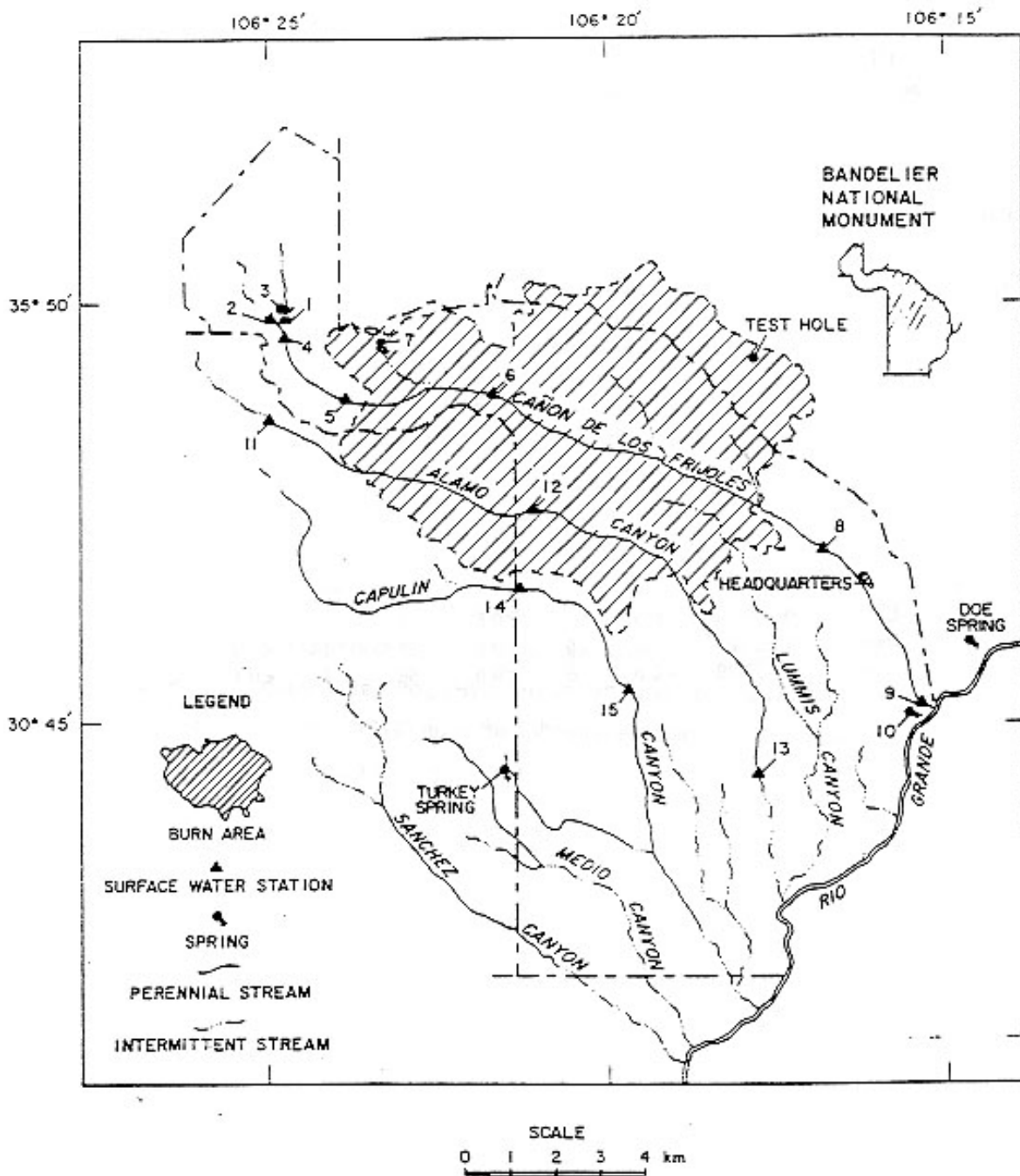


Table 4-7. Water chemistry for streams in Bandelier National Monument in the late 1970s (from Purtyman and Adams 1980).

Table 4-7.
Water chemistry for streams in Bandelier National Monument in the late 1970s (from Purtyman and Adams 1980),
Note: Entries with a * are equal to or less than the listed value

Location	Type of Flow	Date	Ba	Ca	Fe	HCO ₃	Mg	Mn	Pb	Phenol	Zn
Frijoles, Mon. Hdq.	Storm	8-12-77	1.5	164	42	262	9	9.3	0.58	0.068	0.6
	Base	8-27-77	*0.5	100	2.4	92	14	.4	*0.03	*0.005	*0.5
	Base	9-15-77	*0.5	101	0.8	88	13	*0.1	*0.03	*0.001	*0.5
	Base	10-1-77	*0.5	19	0.9	89	6	*0.1	*0.03	*0.001	0.6
	Base	2-8-78	*0.5	3	*0.5	67	1	*0.1	*0.03	0.003	*0.5
	Storm	6-19-78	1.3	58	240	112	28	14	1.0	0.023	1.2
Alamo Canyon	Base	9-1-77	*0.5	87	0.6	80	11	*0.1	*0.3	*0.001	*0.5
	Base	10-6-77	*0.5	20	*0.5	85	5	0.1	*0.3	0.002	*0.5
	Base	6-2-77	*0.5	6	*0.5	95	1	*0.1	*0.3	*0.001	*0.5
Capulin Canyon	Storm	8-17-77	0.8	112	3.7	52	20	1.2	*0.3	*0.001	*0.5
	Base	9-9-77	*0.5	65	*0.5	72	13	*0.1	*0.3	*0.001	*0.5
	Base	4-30-78	*0.5	5	*0.5	81	1	*0.1	*0.3	*0.001	*0.5
	Base	11-30-78	*0.5	6	*0.5	56	7	*0.1	*0.3	*0.001	*0.5

Aquatic Invertebrates

Jacobi (1992) surveyed the stream benthos at three sites in the Santa Fe National Forest, located in the Jemez Mountains adjacent to Bandelier. The survey was designed to establish a baseline biological condition to gauge future impacts of multiple uses of the national forest such as cattle grazing and timber cutting. The three streams in the Jemez Mountains contained an abundance of species of stoneflies, mayflies (including the acid-sensitive *Baetis* genus), caddisflies, true flies, beetles and some mollusks. No chemical data were provided. We would not expect any change in benthic densities or drift rates of aquatic invertebrates in response to deposition. Assuming that water quality in Bandelier is similar in streams found in the Santa Fe National Forest, we do not expect to see invertebrates communities respond to either current or future deposition pH. The buffering capacities of streams in the Jemez Mountain region are high and therefore, we

do not expect acidification of these waters, even under higher loading scenarios. We do not have information on how streams might respond to increases in N loading in deposition.

Amphibians

The following amphibian species have been recorded in Bandelier (Degenhardt 1975): Jemez mountain salamander (*Plethodon neomexicanus*), red-spotted toad (*Bufo punctatus*), Woodhouse's toad (*Bufo woodhousii*), canyon tree frog (*Hyla arenicolor*), and bullfrog (*Rana catesbeiana*). A species list provided by Fleisher (1978) adds the following amphibian species: tiger salamander (*Ambystoma tigrinum*), New Mexico spadefoot toad (*Spea multiplicata*), leopard frog (*Rana pipiens*), and chorus frog (*Pseudacris triseriata*). Larvae of some of these species were observed in temporary pools found on the Monument. The bullfrog is an exotic species that requires deeper, permanent water for breeding and so appears to be limited to habitats along river edges.

There are data from the eastern U.S. that link acidic soils and surface waters with effects on toad, frog, and salamander life history stages (Baker et al. 1990). However, the pH levels that appear to affect amphibian breeding success in the eastern U.S. are considerably lower (less than pH 5.5) than any observed pH of streams or ponds in the Colorado Plateau region (pHs in the range of 7.0-8.0).

Fish

In 1990-91 researchers sampled fish fauna at sites in Los Frijoles Creek (adjacent to park headquarters), the headwaters of Los Frijoles and Capulin creeks, and the Rio Grande between Otowi Bridge and Cochiti Lake. (Platania 1992). Table 4-8 lists the fish species collected in the area (Post 1983). During the 1990-91 sampling the most commonly observed species were flathead chub (*Hybopsis gracilis*) and longnose dace (*Rhinichthys cataractae*), both native species found in the mainstem of the Rio Grande. Two of the four stream drainages sampled in Bandelier yielded fish species, exclusively introduced salmonids (brook, brown, and rainbow trout).

Data from field surveys and experiments conducted in the eastern U.S., Canada, and Scandinavia have identified both salmonid species and cyprinids as being sensitive to both chronic and episodic acidification (Baker et al. 1990; Dennis 1995; Wigington et al. 1996). However, fish responses to acidic episodes were observed only when pHs dropped below 5.5 and aluminum

concentrations exceeded 150 µg/L. These conditions are unlikely to be observed in either the headwater streams or Rio Grande in New Mexico.

Table 4-8. Scientific and common names of fish in Bandelier National Monument and adjacent drainages (Platania 1992).

Common Name	Latin Name
Rainbow trout	<i>Onchorhynchus mykiss</i>
Brown trout	<i>Salmo trutta</i>
Brook trout	<i>Salvelinus fontinalis</i>
Common carp	<i>Cyprinus carpio</i>
Rio Grande chub	<i>Gila pandora</i>
Flathead chub	<i>Hypobsis gracilis</i>
Red shiner	<i>Notropis lutrensis</i>
Fathead minnow	<i>Pimephales promelas</i>
Longnose dace	<i>Rhinichthys cataractae</i>
River carpsucker	<i>Carpionodes carpio</i>
White sucker	<i>Catostomus commersoni</i>
Black bullhead	<i>Ictalurus melas</i>
Channel catfish	<i>Ictalurus punctatus</i>
Mosquitofish	<i>Gambusia affinis</i>
Green sunfish	<i>Lepomis cyanellus</i>
Bluegill	<i>Lepomis macrochirus</i>
Largemouth bass	<i>Micropterus salmoides</i>
White crappie	<i>Pomoxis annularis</i>

Recommendations for Future Monitoring and Research

General recommendations for Class I NPS areas of the Colorado Plateau are provided in Chapter 14. We recommend that NADP and IMPROVE sampling be continued and:

- Continuous ozone sampling be reinstated. The limited information available on ozone at Bandelier indicates levels are commonly higher than on much of the Colorado Plateau, and regional and local air masses that affect Bandelier probably relate poorly to ozone concentrations sampled at Mesa Verde.

- A survey should be conducted to examine for signs of visible injury of leaves from ozone.
- A survey of the chemistry of small streams should be conducted. They are probably well buffered with respect to acidification, but this should be confirmed. If the surface water had moderately low acid neutralizing capacity (less than 200 $\mu\text{eq/L}$), then a long-term monitoring program should be established and maintained for wet deposition inputs and surface water quality.
- The larger streams in Bandelier have been monitored, and are high in ANC; deposition should not lead to acidification. However, chemistry of these streams will respond to changes in soil chemistry that result from wildfires and prescribed burns. The Monument staff should monitor changes in stream water quality following these fires to determine the changes in mobilization of nitrate, sulfate, and base cations that accompany rainfall episodes. This is important to allow a determination of water quality changes that could be traced to changes in deposition vs. land use changes, such as fires.
- The Monument is a participant in the USGS NAWQA program, and we recommend that the natural resources staff review stream water quality data with the USGS researchers on a regular basis to determine if water quality changes are occurring that might signal the need to more intensive sampling and analysis.

Monument Summary

Visibility is currently the only AQRV known to be impacted by pollution, as with the other NPS Class I areas of the Colorado Plateau. Current levels of pollution in north-central New Mexico are high enough to produce haze, obscuring the important vistas of the Monument. Any increase in aerosols will undoubtedly impair visibility further; substantial reductions in aerosols would be needed to restore pristine conditions at Bandelier National Monument.

Little information has been collected on air pollution effects on the Monument's biota. No sign of air pollution impacts on plant or animal species has been reported; ozone concentrations are high enough that some impact is possible for sensitive plants, but SO_2 concentrations are too low to affect plants.

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